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TECHNICAL REPORT

31 December 1949

SOLAR KINEMATOGRAPH AT OAK RIDGE

ONR CONTRACT NO.: N8onr-64801

PROJECT NO.: NR-084-287

CONTRACTOR: High Altitude Observatory of Harvard University and the University of Colorado, Boulder, Colorado

PROJECT TITLE: Development and Construction of High Precision Optical Instruments and Equipment for Use in Solar Research, Including an Equatorial Table and an Eight-inch Coronagraph, or its Equivalent.

SUBMISSION DATE: 15 March 1950.

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INTRODUCTION BY: Walter Orr Roberts

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ABSTRACT

The solar kinematograph installed and tested at Oak Ridge is described. This instrument was dismantled at the time of this report and the knowledge gained will be utilized in the planning of accessories for the Climax 26-foot equatorial Table Coronagraph to be built later.

OUTLINE

I. INTRODUCTION

by Walter Orr Roberts

In a Special Report submitted under this ONR contract on 26 February 1948, Arthur A. Hoag described the plans to build the sunspot kinematograph which has materialized in the later work by Gordon Newkirk, Jr. The camera was described there as a "sunspot sequence camera."

Both Hoag and Newkirk worked primarily as students at the Harvard College Observatory with relatively small charges to the subject contract. Their work has led to designs which will be of assistance in planning later equipment for the large 26-foot equatorial table to be built with funds of the subject contract.

Work under this contract on the kinematograph is considered terminated with this report. Additional development along these lines is planned, however, with the support of AMC Contract W19-122 ac-17. This work will be described in the reports of that contract.

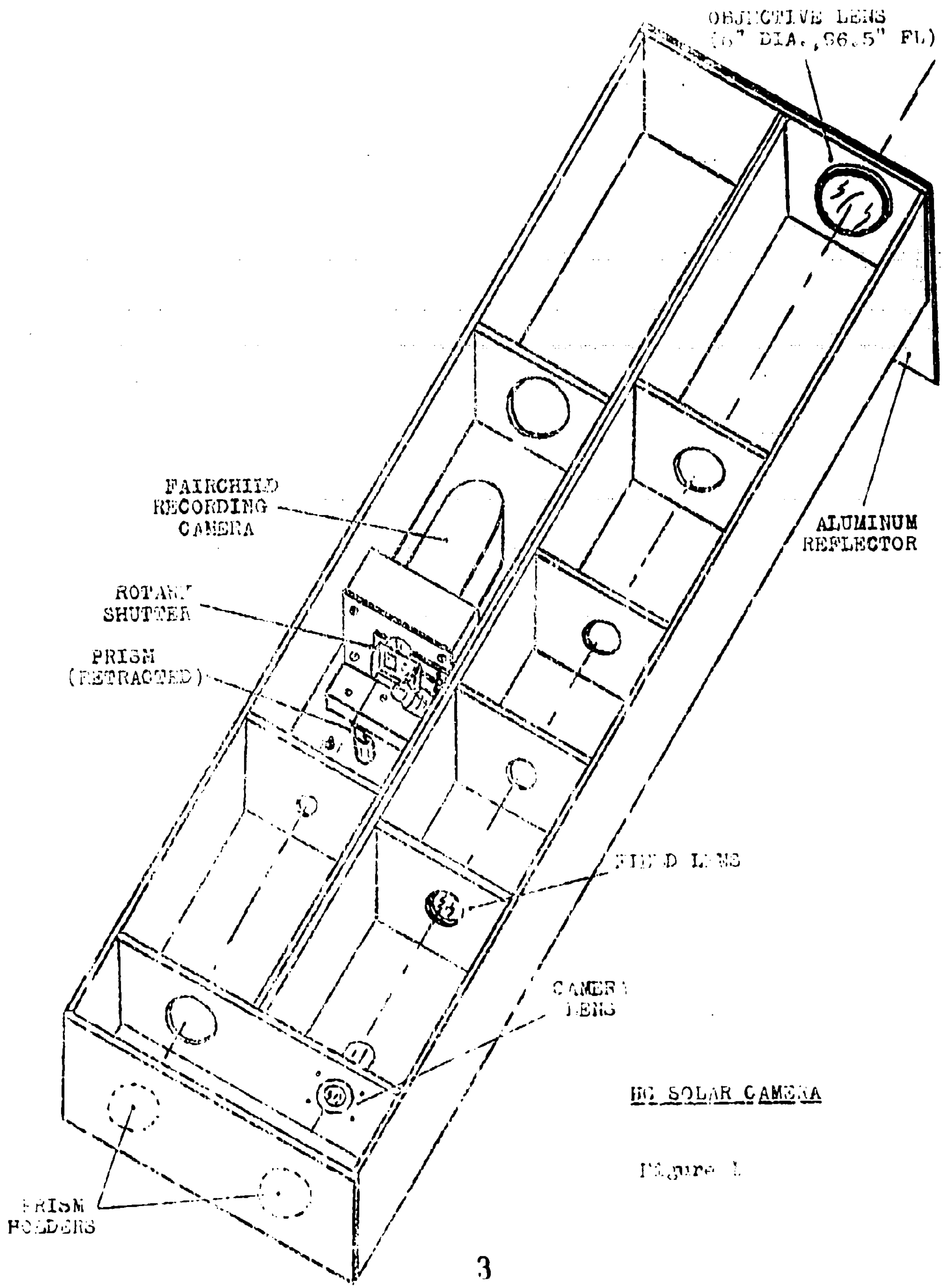
All of the work of Hoag and Newkirk at Cambridge and Oak Ridge fell under the direct supervision of Dr. Donald H. Menzel, Associate Director for Solar Research at Harvard College Observatory. Advice and aid were supplied on some occasions by the High Altitude Observatory research group at Boulder, Colorado.

II. GENERAL DESCRIPTION OF SOLAR KINEMATOGRAPH

The purpose of the HC Solar Camera was to provide a flexible, experimental instrument for solar research. As originally designed by Arthur Hoag, the optical train of the telescope consisted of an objective lens, a collimator lens at a distance equal to its own focal length from the focal plane of the objective, a primary camera lens that was a twin of the collimator lens, and a secondary camera lens that formed the final enlarged image on the film. A birefringent monochromator was to be placed in the parallel light beam between the collimator and the primary camera lens. We found that this optical system was unsatisfactory. The arrangement was extremely difficult to adjust and remained in adjustment only a short time.

In January of [illegible], we revised the optics so that they were in some regards similar to those of a coronagraph. The optical train now consists of an objective lens, a field lens just behind the focal plane of the objective, and a camera lens that forms an enlarged image on the film. The instrument does not employ such refinements as diaphragms to cut off [illegible] from the edges of the lenses, as would be the case in a coronagraph.

A diagram of the complete instrument is shown in Figure 1. The tube of the [illegible] of plywood and is braced with 1/4" steel rods. At the front of the instrument is an aluminum reflector placed to keep the tube relatively cool. The field



HC SOLAR CAMERA

Figure 1

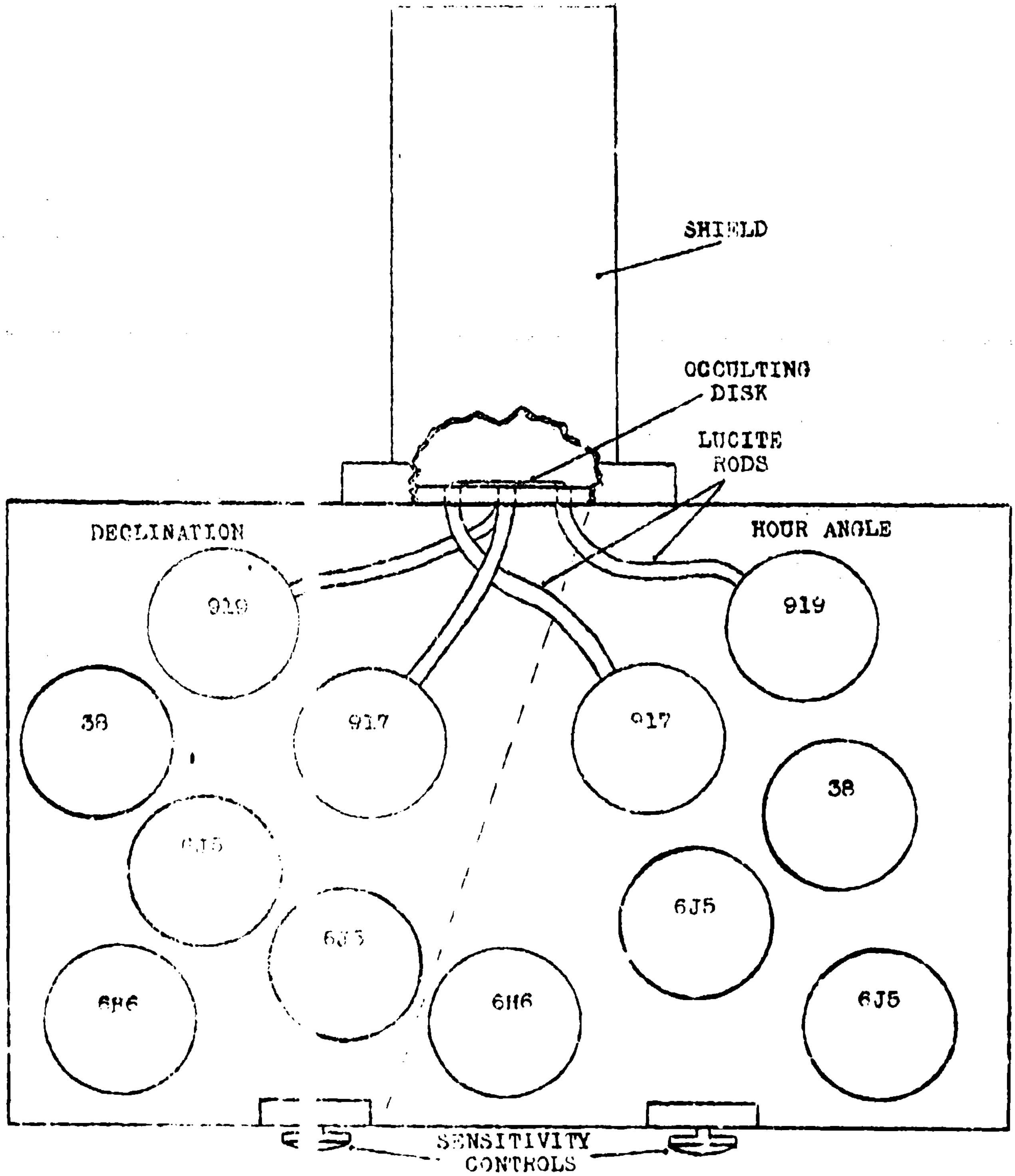
lens is a simple concave-convex lens; the camera lens is a two-inch diameter, 20-inch focal length achromat. Two right angle prisms at the base of the instrument bend the light beam up the left hand side of the tube. The position marked B in the drawing indicates the proposed location of the birefringent monochromator which, at the time of this report, was not completed, and also the location of the color filters which have been used in the kinematograph. Just behind this position is a retractable right angle prism which can be moved into the optical axis to allow the observer to examine the field to be photographed.

A Fairchild Recording Camera supplied by the Office of Naval Research is used as a film-advancing mechanism and magazine. The shutter mechanism consists of a modified Mercury Camera rotary shutter, with a special relay to release it and a 24V DC motor to rewind the shutter spring after each exposure. Both of these pieces of equipment operate fairly well; however, the shutter works stiffly in cold weather, and the recording camera occasionally gives faulty registration of the frames. Photographs with the kinematograph, on file at the Harvard College Observatory, show clearly that the definition of the camera in non-monochromatic light is not particularly good. The cause of this limited definition is that the color curve of the optical system is extremely steep. Unless the light being used for the photograph is essentially monochromatic, the focus will be significantly different from one end of the film sensitivity curve to the other. Even with the relatively narrow pass band of 200 A., the definition is not good. Of course, this difficulty would disappear if a monochromatic filter were used. We made no attempt to make accurate measurements of the scale of the images in the kinematograph since the scale would differ for different wave lengths. The radius of the solar image was roughly 1.25 inches.

III. AUTOMATIC GUIDING APPARATUS

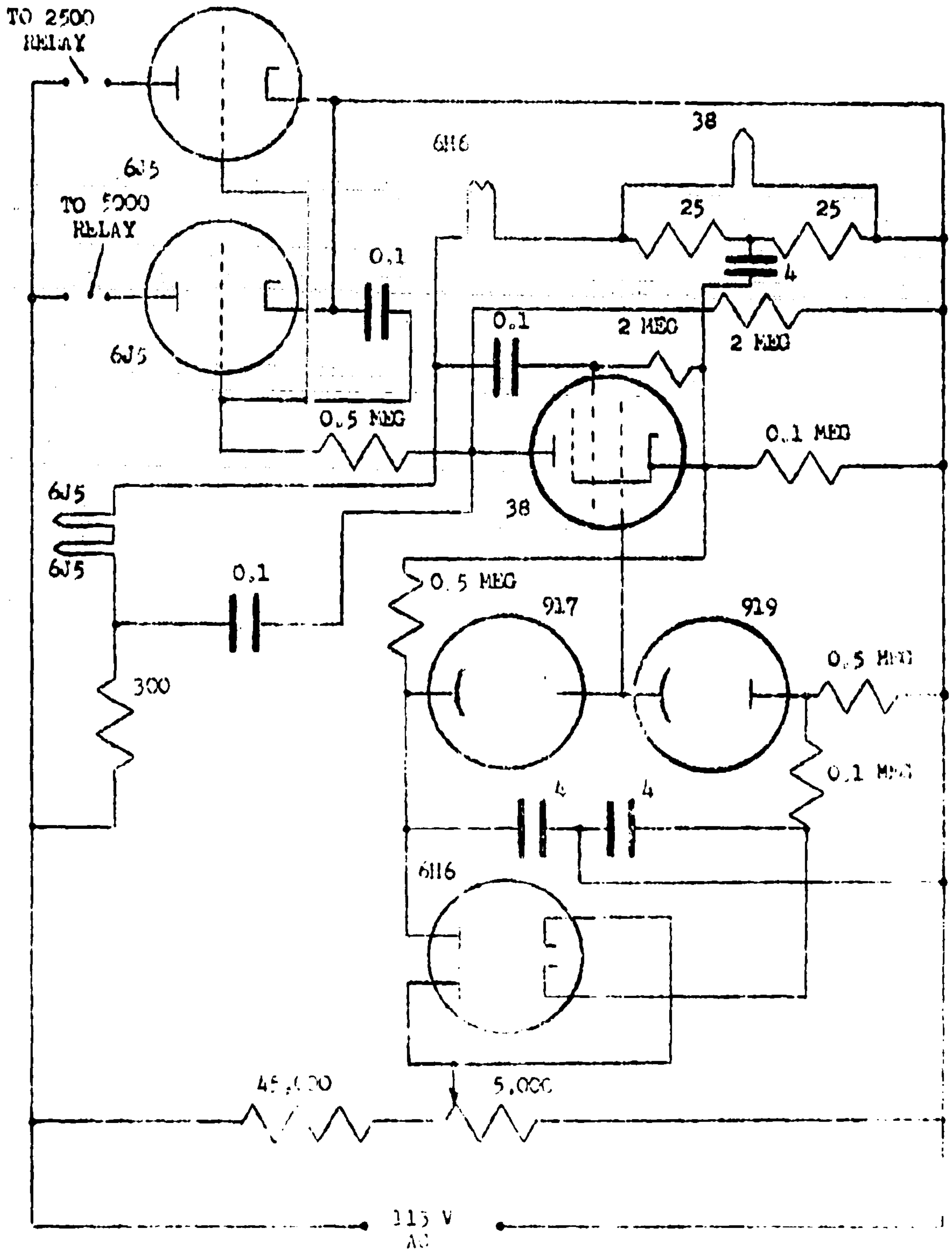
The kinematograph as erected at Oak Ridge is guided photoelectrically by apparatus similar to the phototype guider on the Climax coronagraph[1]. Essentially, the guider (Figure 2) is a second telescope with a detecting device at the focus of a long-focus objective lens. The solar image is centered on an occulting disk that is very slightly smaller than the image. Immediately behind the disk are four lucite rods placed at 90° intervals. These rods, two for hour angle and two for declination, conduct the light to four phototubes. The wiring diagram for one coordinate (Figure 3) shows that the two phototubes are in balanced circuit. When equal light falls on both phototubes they cancel each other, and the first grid of the 38 tube is neutral. Each current does trickle through the 6J5's, however, to close the 5000 Ω relay. It is easily seen that when the 917 phototube receives more light, the first grid of the 38 tube is positive, the current through the 6J5 tubes is higher and both relays close. The opposite effect is produced when the 919 tube receives more light and both

1. "A Photoelectric Guider for Solar Telescopes," Roberts, W. O., Electronics, June 1946



PLAN VIEW of GUIDER

Figure 2



PHOTOELECTRIC GUIDER CIRCUIT
(One coordinate only)

Figure 3

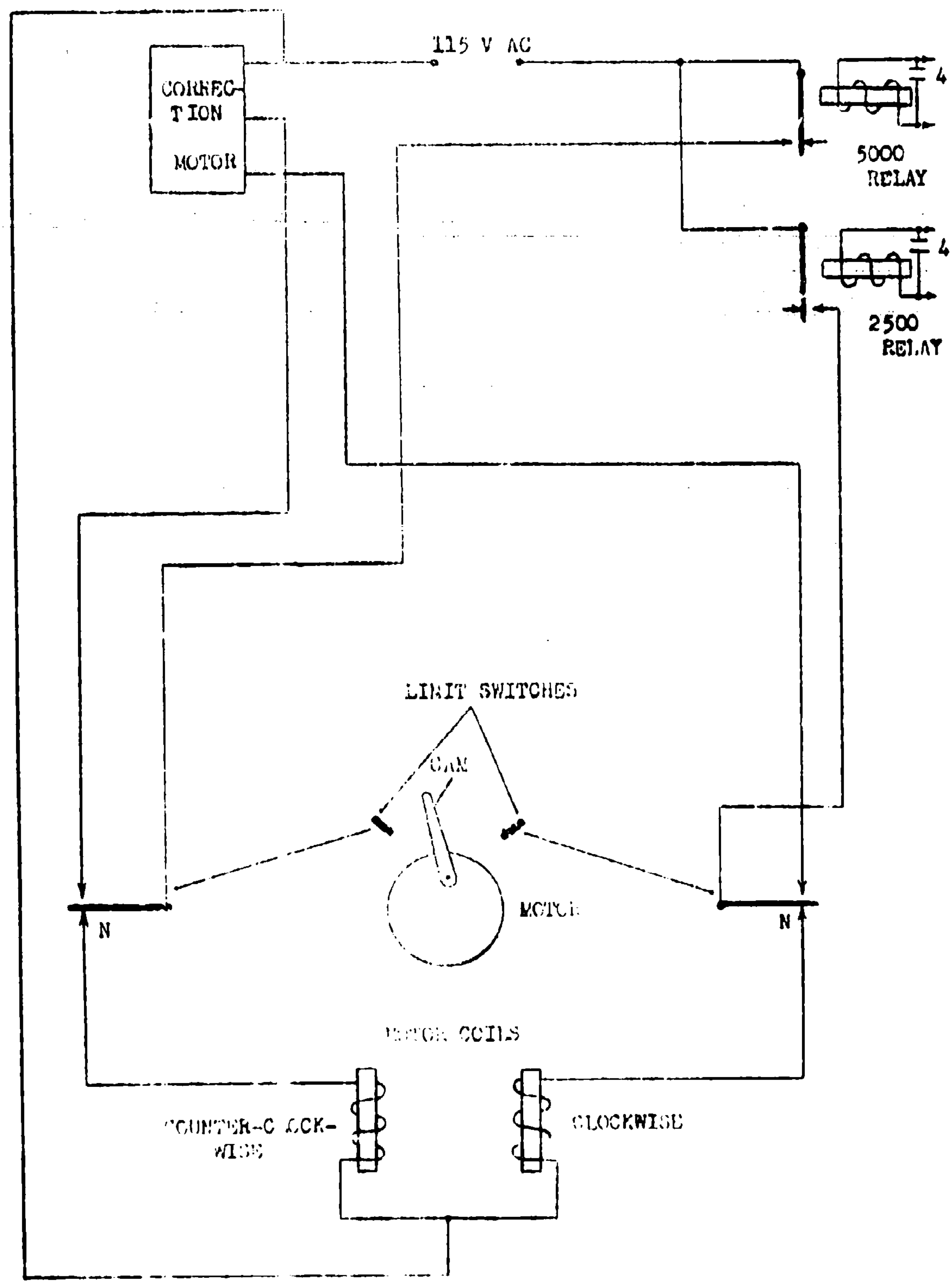
[illegible] of the phototubes is obtained with the sensitivity control which regulates the DC voltage supplied to the phototubes.

It would be possible to have the relays control the telescope correction motors directly; however, according to Roberts, this leads to hunting of the telescope. The anti-hunt unit (Figure 4) is essentially an integrating device that prevents the guider from correcting for random, short period aiming errors but which allows the instrument to respond sensitively to long period errors or the mean of recurring short period ones. Also in the anti-hunt unit box is a voltmeter by which one can check the voltage being delivered to the relays. This is useful in adjusting the sensitivity of the guider circuit. The anti-hunt units for the two coordinates are not identical. For the kinematograph, the hour angle correction motor is controlled by a ten volt DC relay (not shown). A set of AC relays, worked by the limit switches, regulates the ten volt relay. (This arrangement eliminates the common ground between the ten volt current from the station generator and the AC line.)

The declination correction motor is the type which has four leads arranged so that they must be switched around to reverse the motor. (That is, for clockwise motion, white must be tied to black and green, to blue; for counterclockwise motion, white to green and black, to blue.) To use this motor we had to have two limit switches where there was previously only one. The two switches at each end of the adjustable cam are arranged so that they are both thrown at the same time. This arrangement of the correction motors would not be used in a permanent arrangement. These modifications in the anti-hunt units are not included in the wiring diagram. Actually on the Climax Equatorial Table Coronagraph, to which the principles studied here will be applied, the guider the the coronagraph will perform this work. The guider is planned to be a continuous servo of far more complex design than this one.

To have the guider follow the sun while the kinematograph is pointed at any region of the solar disk, it is necessary to have some means of [illegible] the axis of the guide telescope to the axis of the main camera. This is done by an image shifter. The image shifter is a piece of plane parallel glass two inches thick mounted so that the normal to the glass may be moved in both the hour angle and right ascension directions. This device merely shifts the solar image from the guide telescope and has the effect of changing the position of its axis relative to the axis of the kinematograph. The device is [illegible] and has proved quite satisfactory.

The [illegible] guider has worked successfully. When [illegible] it will respond to an error of about a second of [illegible] of about the same amount. The [illegible] to be limited mainly by seeing [illegible] to use two occulting disks, [illegible] (slightly smaller) for summer use. The [illegible] in adapting the guider for another [illegible] to move slowly enough [illegible] rate (1° per minute) is [illegible]



ANTI-HUNT UNIT (One coordinate)

Figure 4

IV. ELECTRICAL CONTROL EQUIPMENT

A. Main Control Circuit

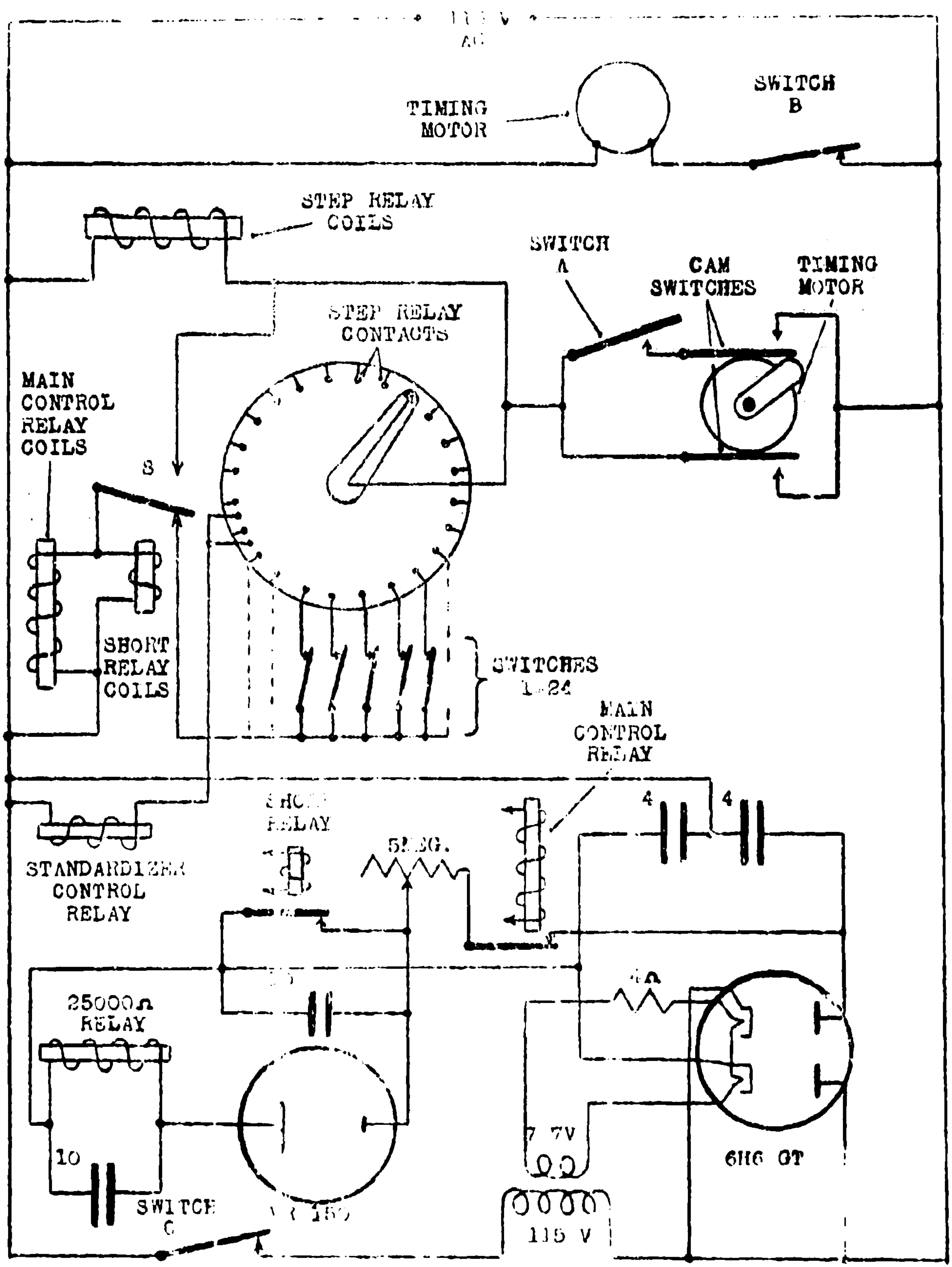
A drawing of the main control circuit is shown in Figure 5. The function of the unit can easily be seen from the circuit diagram. The top of the drawing comprises a timing circuit in which the timing element is a synchronous motor. A switch S is arranged so that the main control relay may receive a pulse directly from the cam switches or remotely through the step relay (40 steps). Switches 1-24 allow one to connect various contacts of the step relay to the coils of the main control relay. By this arrangement it is possible to have intervals from 7½ seconds to ten minutes between exposures. The switch combinations for various timing intervals appear in Table I. (The errors in these times are of the order of 0.1%.)

TABLE I

Interval	S	A	B	C	1 through 24
7½ sec	L	U	U	U	———
15 sec	L	D	U	U	———
30 sec	R	D	U	U	1,2....20 up
60 sec	R	D	U	U	1,3,5...19 up
75 sec	R	D	U	U	1,5...20,21..24 up
2 min	R	D	U	U	1,5,9,13,17 up
150 sec	R	D	U	U	21,22,23,24 up
5 min	R	D	U	U	1 and 11 up
10 min	R	D	U	U	1 up

L - left R - right U - up D - down

The second half of the control circuit is merely a delay switch to enable the vibrations caused by the film advance solenoid to die down before the shutter is opened. To produce the delay, the shutter is set off by a 25,000Ω relay that is closed by a relaxation oscillator. When one pole of the main control relay closes, the 6H6 voltage doubler rectifier tube charges, through a variable resistor, a ten mfd condenser in parallel with a VR 150 voltage regulator. The VR 150 allows the voltage to build up to a critical value and then discharges the condenser through the 25,000Ω relay, which closes to set off the shutter. In order to prevent the accumulation of errors in the oscillator, a shorting relay is arranged to discharge completely both the condenser and the VR tube at the end of each exposure. This device gives a maximum practical delay of about a second.



MAIN CONTROL CIRCUIT

Figure 3

B. Shutter Circuit

The operation of the shutter set and release circuit can easily be seen in Figure 6, and little explanation is necessary. The single pole 24V DC relay will stay closed once it is closed and will keep the shutter rewind motor going until the cam switch breaks the circuit. This cam switch is on the shutter and does not open the circuit until the shutter is completely wound. The 1, 2, ... 5 refer to the lead connections from the shutter unit to the control box.

C. Standardizer Circuit

The photometric standardizer is simply a small, transparent step-density wedge that can be moved into the field of the camera lens. The step-density wedge is contained in a $1\frac{1}{4}$" diameter cylindrical box and is illuminated by the light from the solar image plus that from four small lamps. To diffuse the light, a piece of opal glass is placed immediately behind the density wedge.

The purpose of the standardizer control circuit (Figure 7) is to move the step density wedge into position, turn on the lamps, and then move it out of position once the standard frame is taken. One sees in the main control circuit (Figure 5) that the coils of the standardizer relay are connected to two off contacts of the step relay, i.e., two contacts on which an exposure would never be taken. At the first contact the motor moves the density wedge into place and the lights go on. At the second, the exposure is made. At the third step relay contact the motor moves the density wedge out of the field and shuts off the lights. Screws on the shaft holding the cylindrical box operate the limit switches. These screws can be adjusted to stop the density wedge box at the proper position. A', B', C', and D' refer to the leads of the motor; A, B, C, and D, to the plug [illegible] at the standardizer. It will probably be [illegible] the intensity of the light on the [illegible] when it is used with the monochromator.

V. [illegible] FILTER, [illegible]

The birefringent monochromator being built for us by Baird Associates is to be a split [illegible] filter of [illegible] pass band. Ammonium dihydrogen phosphate [illegible]. In order to have the filter tunable over a small range of wave lengths about the normal maximum at 6562.8 Å, the two thickest [illegible] with two fractional wave plate and polaroid [illegible]. With the polaroid in one position on a fractional wave plate [illegible] maximum retardation; with the polaroid 90° from this position, the retardation will be zero. One thus effectively has a retarding plate of variable thickness.

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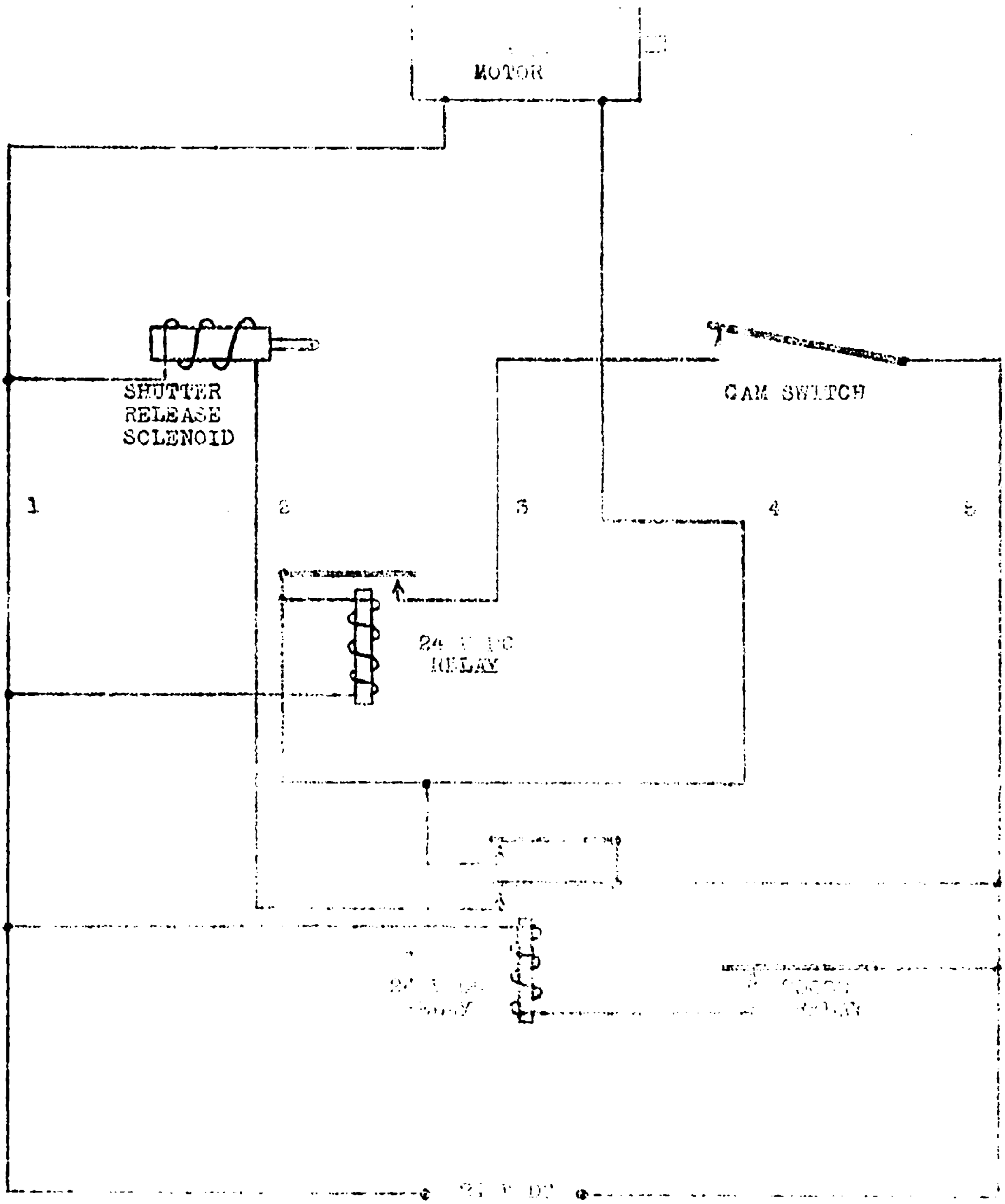
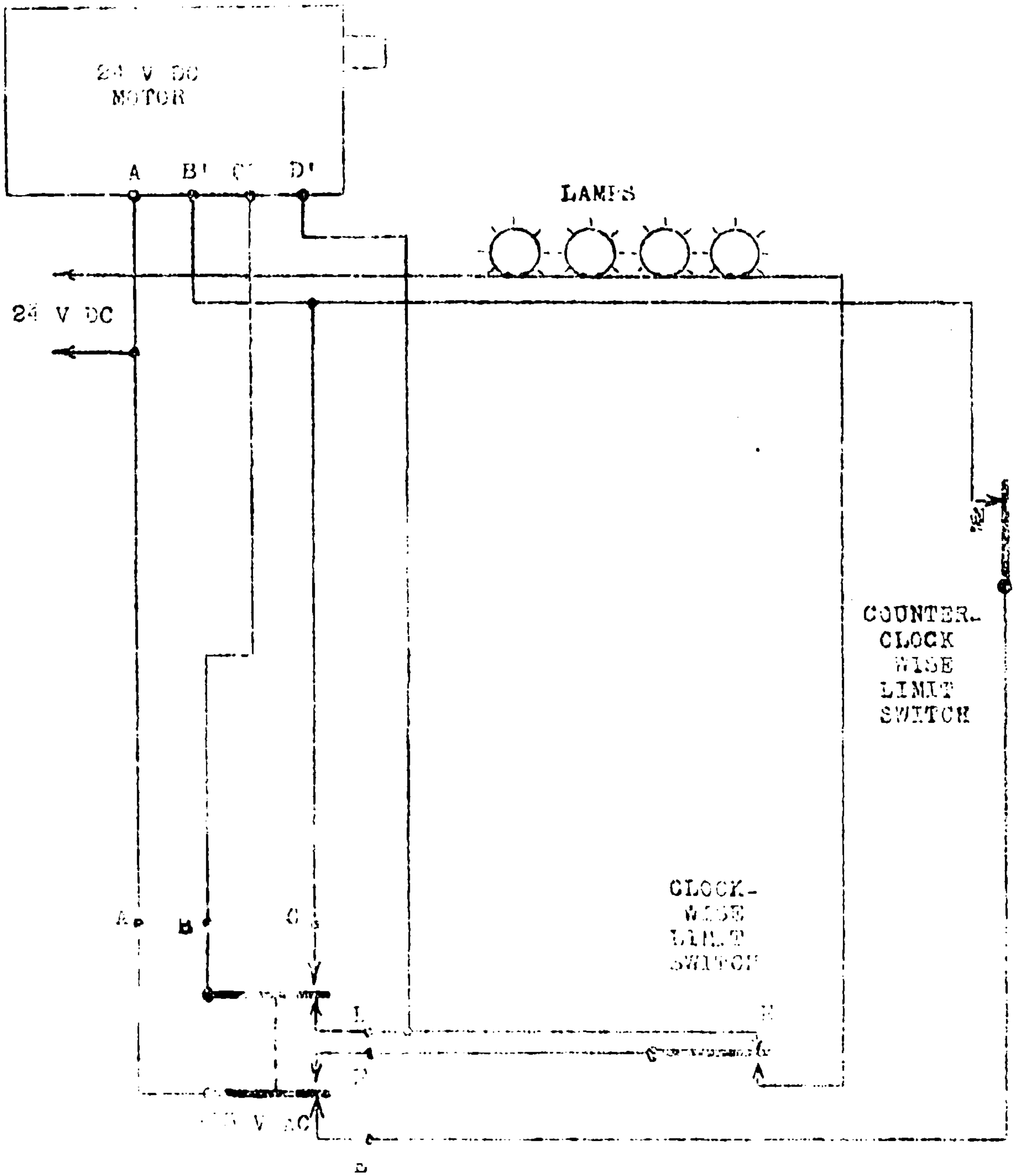
1. "The Birefringent Filter," [illegible], J. Opt. Soc. [illegible], No. 3, 1949



[illegible]

Figure 6



ST NDARDIZER CONTROL CIRCUIT

Fi ur 7

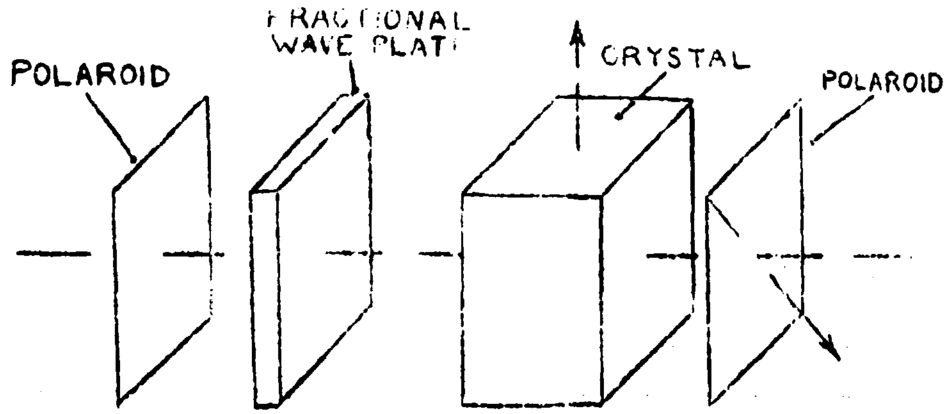
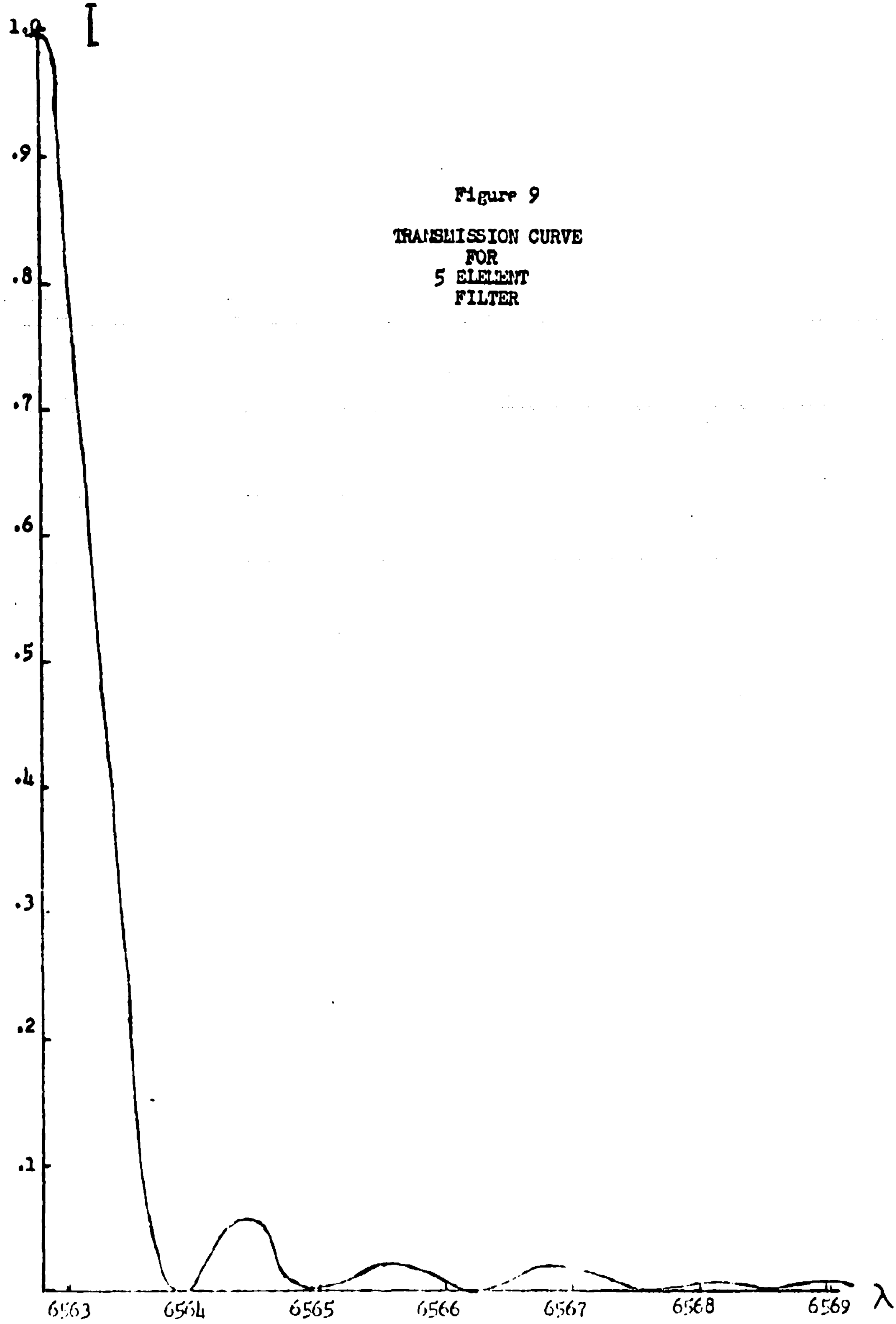


Figure 8

Consider the unit (Figure 8) consisting of the thickest crystal, one of its polaroids, the fractional wave plate (let us take it to be a half-wave plate), and a second polaroid. By turning the half wave plate and the second polaroid one can add various amounts of retardation to that of the thickest plate. Since the plane of polarization of the emergent light makes an angle of $2\pi - 2\theta$ with the plane of polarization of the incident light (where θ is the angle between the incident vibrations and the principal section of the half-wave plate) a gear train will be needed to turn the polaroid and half-wave plate combination through twice the angle turned by the half-wave plate alone. A similar unit involves the second thickest filter plate. (The rotation of this unit must be mechanically coupled to the first.) By adding various retardations to the two thickest crystals, we may shift the maxima of these two plates up and down the spectrum. In practice the sharp peak from these two plates is moved about "inside" the peak of the third thickest plate. Of course, the amount that the sharp peak may be moved depends upon the residual light that appears at other wave lengths as the maximum is displaced from its original position. Figure 9 shows the pass band of a five element filter that is "shifted" about .1 Å from 6562.8 Å.

In the practical use of a monochromatic filter it is necessary to be able to find the position of the maximum in the spectrum. Even with an electrically "tuned" filter, one would like to know if the maximum were at the normal position (in our case 6562.8 Å) and use this as a fiducial point. The simple monitoring system, planned for the kinematograph consists of a Fabry-Perot interferometer as an analyzer and a hydrogen tube for a source of standard wave length (Figure 10).

At the time of this report, neither the filter nor monitor device have been built.


1.0
I
.9
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.7
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Figure 9
TRANSMISSION CURVE
FOR
5 ELEMENT
FILTER
6563
6564
6565
6566
6567
6568
6569
λ

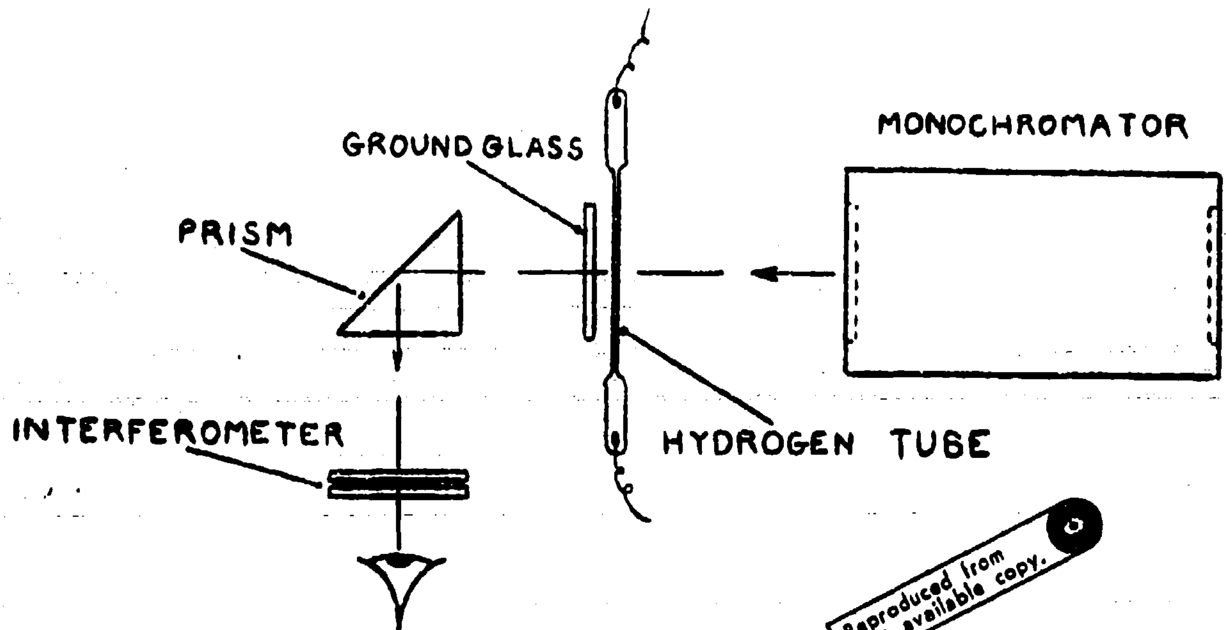

Figure 10

Light from the monochromator and from the hydrogen tube will fall on a ground glass diffuser. When an observer looks through the interferometer, he will see the fine fringes from the hydrogen tube superposed on the broader fringes from the monochromator. Setting the filter on 6562.8 Å will be merely a matter of moving the broad fringes until they appear to be bisected by the sharp fringes.

Since the monochromator was not to be ready for the summer of 1949, I experimented with a Baird interference filter (with normal incidence maxima at 3970 Å and 5235 Å) and some sharp cut-off glass filters in an attempt to find a combination with a fairly narrow pass-band. Copies from microdensitometer tracings of some of these experiments are shown in Figure 11. These are tracings of plates made on the Oak Ridge spectral standardizer (with narrowest slit width) with 103 aF plates and an incandescent bulb as a light source. The filter combination was placed in front of the slit. A short exposure on a mercury arc with the filter and light bulb removed was used as a wave length standard. Figure 11 A shows a tracing of an exposure with the bulb and mercury arc alone. Figures 11 B and C are tracings of a red glass filter and the Baird filter separately. Note that the Baird filter placed 65° from normal incidence produces two maxima, which are polarized in opposite directions. The low height of the maximum marked A is apparently due to some polarization of the light going through the spectrograph in addition to the drop in the intensity of light emitted by the lamp. One can see in Figures 11 D and E that the attempt to improve on the pass band of the Baird filter by combining it with the glass filter was hardly successful. (The exposures of A through D were the same - that for E was increased by a factor of 3.)

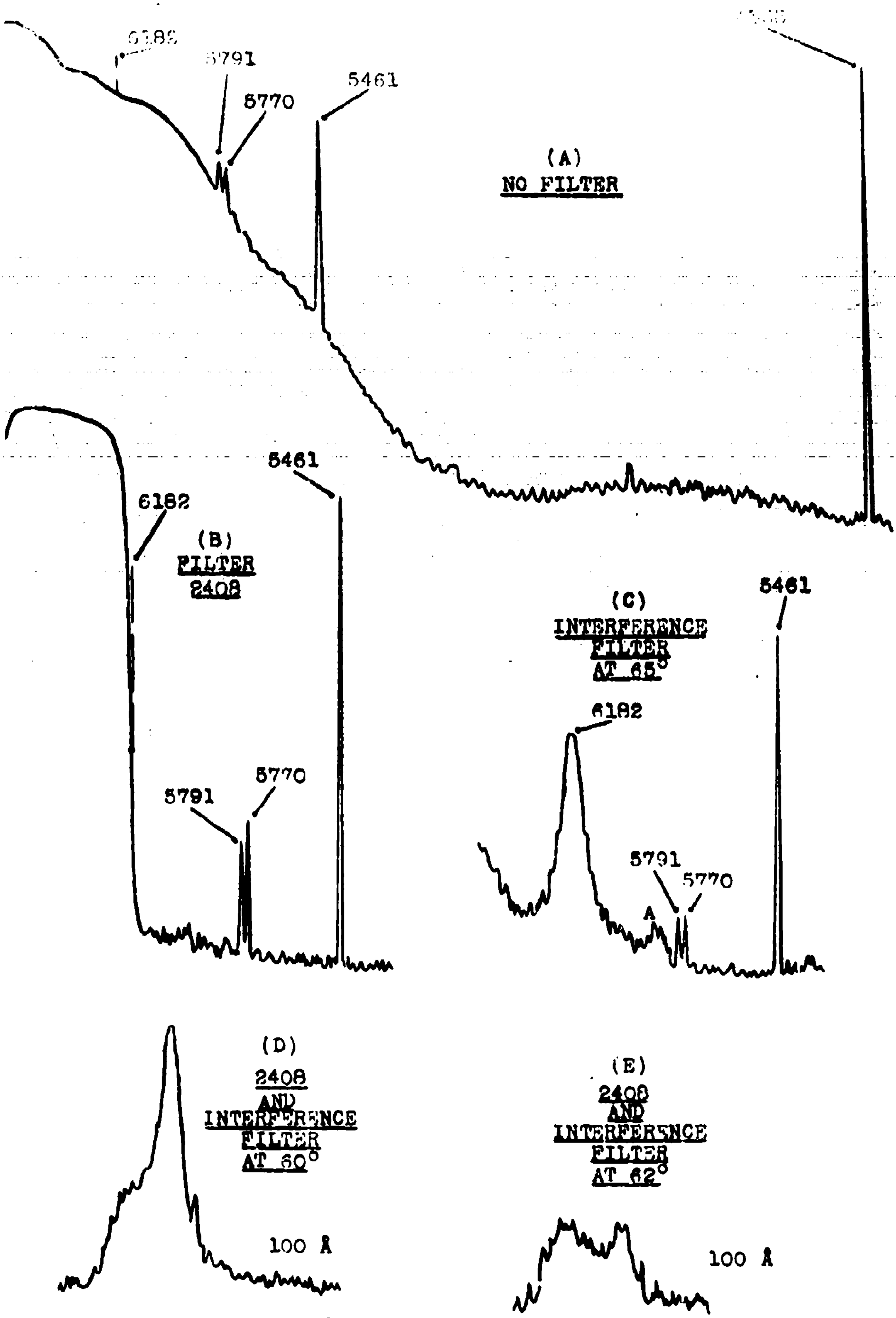
6182
5791
5770
5461
(A)
NO FILTER
5461
6182
(B)
FILTER
2408
5791
5770
5461
(C)
INTERFERENCE
FILTER
AT 65°
6182
5791
5770
A
(D)
2408
AND
INTERFERENCE
FILTER
AT 60°
100 Å
(E)
2408
AND
INTERFERENCE
FILTER
AT 62°
100 Å

Figure 11

VI. CONCLUSIONS

The experimental kinematograph has been dismantled to make room for the 24" reflecting telescope. As a whole the HO solar camera will not be used again; however, the various pieces of auxiliary equipment will be useful for later experiments at Oak Ridge, Boulder, or Climax. The information gained here will be used in planning the accessories for the 26-foot Equatorial Table Coronagraph that will be installed at Climax, probably in 1951, and on other solar equatorial tables planned for Climax.

VII. ACKNOWLEDGEMENTS

I should like to express my special appreciation to Dr. Donald H. Menzel and Dr. Walter Roberts for their advice and patience in this work. Also I want to thank Dr. Shapley and Dr. Bok for permitting me to work at Harvard Observatory and the Oak Ridge Station. Joyce Marrison deserves thanks for her work and encouragement during the progress of the project and for typing this manuscript. My thanks also go to Arthur Hoag and the staff of Baird Associates. Finally I should like to acknowledge the assistance of the Office of Naval Research. ONR financial support made the project possible.

Gordon Newkirk, Jr.

Approved for Submission as
Technical Report

Walter Orr Roberts

Walter Orr Roberts

15 March 1950